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COMPUTER-BASED INTEGRATED ASSISTANCE FOR COORDINATE MEASUREMENTS

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Abstract – The constant increase of the application areas of coordinate metrology is due to the universality and flexibility of coordinate measurement machines (CMMs). Their varied applications require a high degree of knowledge by the CMM operator. In coordinate metrology, the operator is the main cause for uncertainties. The aim is to achieve small uncertainties, so that reliable and predominantly operator-independent measurement results can be obtained. To reduce these effects, it is necessary to support the CMM operator during his measuring tasks.

Keywords: Coordinate Metrology, Assistance System.

1. INITIAL SITUATION

The constant increase of coordinate metrology is due to its universality and flexibility. In addition to 3D length measurement, CMMs are also used to execute form tests and to digitise unknown surfaces. Their varied applications require a high degree of knowledge by the CMM operator, so as to achieve measurement results with the smallest possible measurement uncertainty. Measurement deviations in coordinate metrology are caused by the operator, environment, workpiece and CMM.

1.1. Influences on measurement results

It can be assumed that the influencing factors operator – environment – machine have a relative importance of approximately 100:10:1 in causing deviations [1].

The technology of the hardware today is such that uncertainties of 1 to 2 µm, in some cases, even smaller, are state of the art. Monitoring of inspection, measurement, and test equipment with calibrated test pieces ensure long-term stability of the test results and traceability to national and international standards. The correctness of measuring software is evaluated by the determination of reference data records and the comparison with reference software.

Using specified materials and establishing defined constant conditions can minimize uncertainties caused by environmental influences. It is, to some extent, possible to compensate the influence of the environment computationally. The influences emanating from the workpiece are caused by the existing shape deviations (form deviations, waviness). For a function-oriented determination of these deviations, special evaluation criteria are required (Least Square Condition, Maximum Inscribed Condition, Minimum Circumscribed Condition, Minimum Zone Condition), which are available in many measuring software packages meanwhile.

Comparison of measures for reduction of the influences by the separate factors shows that for the factor that can cause the largest measurement deviations and measurement uncertainty – namely the metrologist – only few concrete measures exists. The metrologist is responsible for fixing the workpiece, for determining of the measurement strategy consisting of probing strategy, probe configuration and use of facilities as well as for the evaluation strategy.

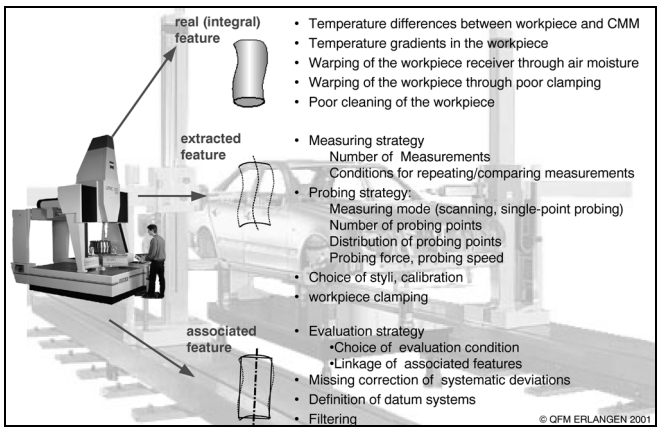

Fig. 1: Users´ influence on measurement results and uncertainty

To achieve low deviations that are reliable and largely operator-independent measurement results, it is necessary to place the emphasis of the development on the operator. In addition to solid training of the CMM operators, another way of reducing the operator influence on the measurement result is to provide the operator with direct support during the measuring process.

1.2. State of the art of training in Coordinate Metrology

Training courses for operators of CMMs are usually held by the machine manufacturers. Their focus is on hardware and software details. Far too little time is given to teaching basic metrology and imparting knowledge of standards.

Even if efforts are being made to rectify this deficiency with a manufacturer-independent training concept for coordinate metrology [2], there is still the disadvantage regarding the lack of practical reference. The problems then occur after the training during the practical application of the knowledge learned while performing measurement tasks. The whole range of ever more complex functionality of CMMs is only dealt with in a fragmentary way in these courses.

For companies, conventional training courses are a significant cost factor [3]. Moreover, training courses are bound to fixed dates and localities and are not available to the user "just in time". The user, on the other hand, can call up an integrated assistance system at any time and at any workplace. The user no longer has to leave his place of work to obtain knowledge, thus eliminating additional costs.

1.3. State of the art of assistance for CMMs

Existing advice and assistance systems, inasmuch as there are any, are usually no more than online help systems and assistants that provide support when writing measurement procedure programs. They explain the syntax of the device's own programming language or automate working steps, with the effects, however, often remaining unclear. In some cases, help systems are no more than digital manuals. None of the current systems support the user with expert performance of his measurement tasks in a holistic way. In the way they impart information, these systems have little specification of the users, providing every user with the same help regardless of his level of knowledge and his tasks.

1.4. Deficits and Requirement of Assistance Systems

An advice and assistance system that supports the user actively in correct processing of his measurement tasks must meet higher demands than are met by the systems currently implemented. Such a system must not limit the support it offers to programming help. It must support the machine operator and measurement planner with all steps: analysis of measurement tasks, planning and execution of measurements, evaluation and representation of the results. The provided information must be accessible on the measuring machine and understandable to every user at any time and in a simple way. That requires that such an advice and assistance system is capable of user-sensitive adaptation regarding the individual requirements for information and support. The user must be provided with an intervening system within the assistance system in order to control interactively the breadth and depth of the information offered. It must also be possible for the user to add information to the existing assistance system.

We can also expect, that assistance is offered to the user according to situation and context, in order to provide only information and support which is required for the measuring task at hand.

Individual requirements are fulfilled by current help systems but none meets all the requirements of a complete advice and assistance system.

2. CONCEPTS FOR ASSISTANCE FOR CMMS

A comprehensive assistance system for coordinate measurements has to provide active support for the analysis of measurement tasks and for planning and executing measurements as well as for the presentation and evaluation of the results.

2.1. Determination of knowledge base

In a first approach the knowledge base of CMM users was determined that is necessary for professional execution of measurement tasks. Based on the knowledge of coordinate metrology and its adjacent branches, which has already been put together at the Chair Quality Management and Manufacturing Metrology, on the basis of a literature study and a review among industry professionals, a master guide for coordinate measurements was developed. Subsequently the required knowledge for each step of this uniform procedure has been investigated and set up in a base plan for “Good Coordinate Measurement Practice” (Fig. 2). This base plan is also used as the training concept for Coordinate Metrology in Germany [5].

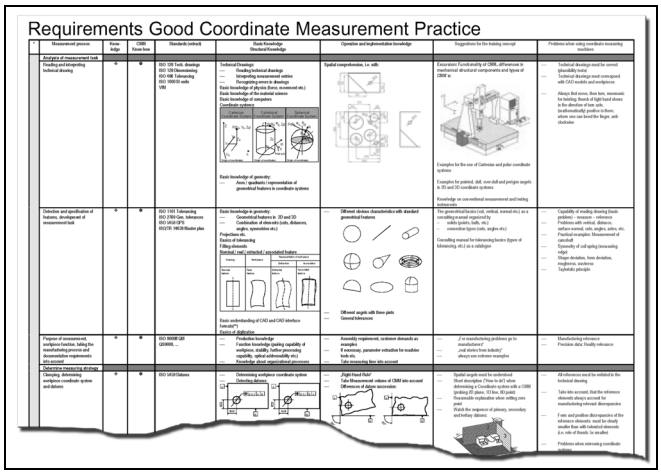

Fig. 2: Base plan for “Good Coordinate Measurement Practice”

It is necessary to make a distinction between the types of information to be imparted. The didactic presentation of action knowledge is different from that of structural knowledge or knowledge of standards. Action knowledge, such as the use of the "right-hand rule" to find the coordinate direction, is most easily imparted using illustrations. Structural knowledge, on the other hand, such as the orientation of the coordinate systems in space is easily described verbally or mathematically.

But it is not enough just to divide the information into action knowledge and structural knowledge. It is also necessary to distinguish between background knowledge that is essential for processing measuring tasks and additional information that contribute to a better general understanding of metrology.

In the base plan the knowledge contents have been subdivided according to standards, basic knowledge, action knowledge, suggestions for in-depth excursions and typical execution problems. In addition, the knowledge has been

divided into the subcategories basic knowledge and special knowledge of coordinate metrology as well as into device-dependent, proprietary and into device-independent, non-proprietary knowledge.

2.2. User sensitive assistance

We can expect a user-sensitive assistance system to present the required information depending on the profile of the user. A simple machine operator requires extensive assistance, including learning options close to the workstation, for example, to be able to decide reliably between scanning or single point probing. When using the scanning method, an experienced and trained measurement engineer only requires information about parameter optimisation or estimation of the measurement uncertainty.

Therefore, such an advice and assistance system must be able to decide between the different user profiles that have differences on the levels of knowledge, the field of functions and practical experience of the user. The fields of application and qualifications of these user profiles have been described within in a three-step model, which has become standard in practice [5]. These designed profiles are the CMM-User, who runs completed measurement programs, the CMM-Operator, who can modify measurement programs and perform simple measuring tasks himself, and the CMM-Expert, who performs complex measuring tasks and makes decisions (Fig. 3).

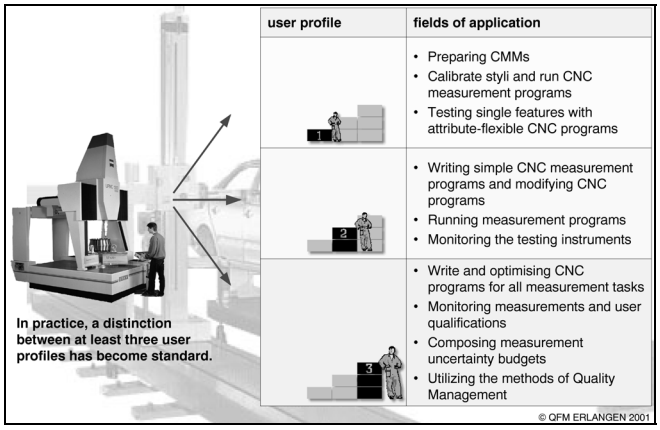

Fig. 3: Different profiles of CMM users and fields of application

2.3. Components of assistance systems

An advice and assistance system must therefore present its support in various ways to assist the user during his measuring tasks in a context-sensitive way. Due to the modular structure of the assistance system each CMM user group can be addressed in a different way depending upon the user profile [4].

Using various, also multimedia-type assistance modules (Fig. 4), it is possible to provide an assistance system that offer users with different profiles individual task-related support and gives them the necessary knowledge.

Each of the modules shown in Fig. 4 is especially suitable for imparting structural knowledge, action knowledge, additional information, or background knowledge, such as metrological background knowledge and knowledge of standards [4]. Each addresses the different user profiles differently.

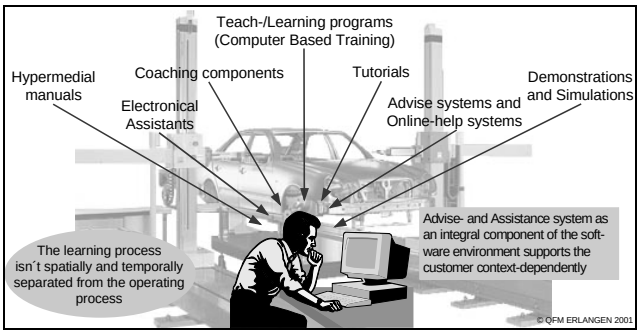

Fig. 4: Components of an Integrated Assistance System

For example, electronic assistants are used for work processes where the only aim is to solve the task without the necessity of informing the user of the background and technical details. They are mainly used to catch incorrect or missing input or parameters and to ensure sequential execution. Starting a coordinate measuring machine is a typical example. It is usually necessary to perform numerous actions that must be performed in a certain sequence. An assistant for the starting procedure monitors the sequence and ensures that the inputs are complete. At the same time, on the basis of a user login, it can assign a user profile to the user or load his personal profile, containing information about his level of knowledge, his field of functions or his practical experience. To start the measuring machine, the user does not have to be informed about the background of the sequence of operations, it is only necessary to ensure that the sequence is that he abides by.

Tutorials are especially suitable for providing introductory knowledge of standards, basic knowledge, and action knowledge about extensive topics. They provide the user with an initial introduction to the problem at hand, for example, about selecting the correct evaluation criterion for determining the form deviations. After that, the user selects the necessary information, such as extracts of standards with an explanation or learning units about evaluation criteria and form testing that teach him the minimum zone method as the standard-compliant evaluation criterion for form testing. The information is presented to him interactively in small steps. Afterwards he can check his level of knowledge and obtain a course certificate. The initial extra work time spent using the tutorial quickly leads to timesavings due to faster processing times and reliable operations of the CMM. Tutorials are especially suitable for the user profiles CMM-Operator and CMM-User.

If the technical subject matter to be explained is very complicated, demonstrations often provide an excellent illustration. They are especially suitable for representing self-contained action sequences, for example, a video description of a scanning procedure at the CMM. Photos and movies link theory with practical work. The user can recognize the real environment of the CMM. Demonstrations are above all suitable for imparting action knowledge, but they do not permit any interaction by the user.

These examples show that individual modules are especially suitable for presenting some of the types of information described, depending on their characteristics. The most suitable module can therefore be selected and implemented to provide the information required.

2.4. Ways of providing information

The provision of information at a workstation can be implemented in different ways. For example, the assistance system can be integrated into the system of the CMM. Or, knowledge can be provided through a web-based assistance system. Both ways have their advantages and disadvantages.

With an assistance system integrated into the machine it is easier to provide information specific to the machine because it is possible to create an individual assistance system for each type of machine, which, for example, can deal with the special features of processing measuring tasks on that particular measuring machine. In addition, only with an integrated solution a context-related assistance can be realized which needs information about the stand of the measurement task processing. The broadness of such assistance solutions is restricted by the programming effort required for each machine type. Because they are integrated, such assistance solutions can only be developed in close collaboration with the CMM- and measuring software manufacturers.

Web-based information has the advantage that it can be implemented simply and without any restrictions imposed by the machine system. This way, providing information is also independent of the platform of the CMM software. In particular, multimedia assistance modules can be implemented web-based. The disadvantage is that the machine-specific knowledge can be very broad because of the variety of types of CMM. On the other hand, it is an efficient way of providing and updating machine-independent basic knowledge for performing measuring tasks on the web.

An assistance system with comprehensive functionality can only be implemented with a combination of these and other concepts.

3. DEVELOPMENT OF ASSISTANCE SYSTEMS

The development of a comprehensive advice and assistance system is a complex procedure, which requires use of interdisciplinary knowledge apart from compiling information about the coordinate measurement practice

Therefore experts of different tasks and disciplines have to be included in the development procedure; primary coordinate metrology experts as well as secondary psychologists, computer scientists and CMM manufacturers.

The whole procedure of assistance solution development consists of three main phases: planning, implementation and evaluation. The planning phase is the phase of “prediction” which includes collecting all necessary information that is needed in development phase. The implementation phase is the phase where assistance modules are formed and connected in comprehensive assistance solutions. The evaluation process gives information about the real capability of the assistance solution components and sometimes reveals that some of the assistance modules need to be improved in part, the development procedure. The final product is a comprehensive computer based advice and assistance solution that satisfied all requirements defined at the beginning of planning phase.

Step by step, the procedure of forming such assistance solution is presented in figure 5. It can be shown as a guideline for the methodical procedure of developing an advice and assistance system.

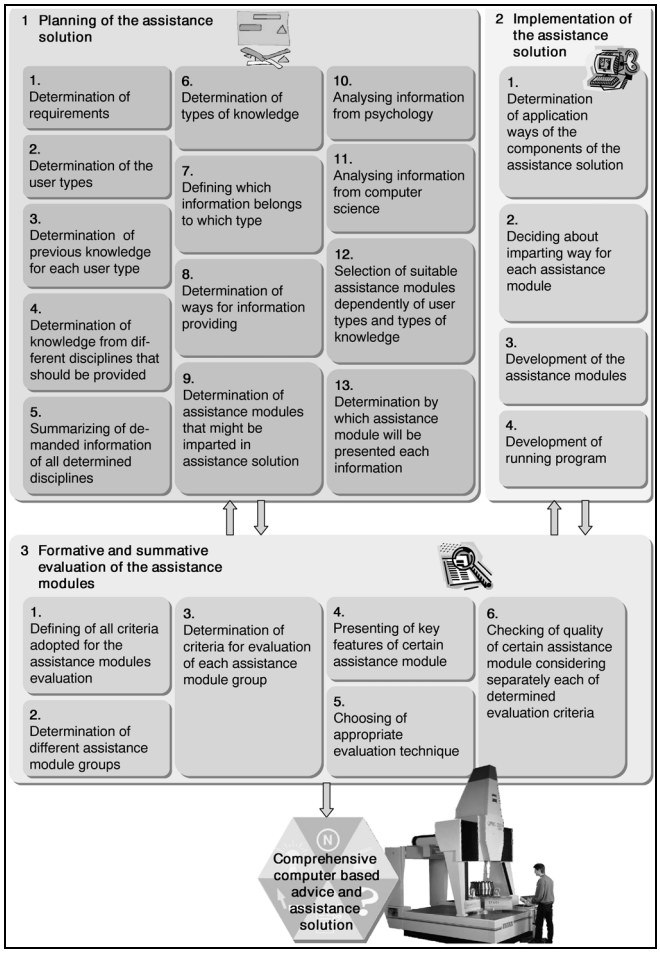

Fig. 5: Guide for methodical development of assistance solutions

3.1. Planning phase

The development of an assistance system starts with the planning phase in which all requirements and boundary conditions as well as the information to be represented have to be analyzed. Then, the gathered data has to be sorted and structured. For an advice and assistance system for Coordinate Metrology these work steps were carried out. The results have influenced the base plan for “Good Coordinate Measurement Practice”.

The next step in the planning phase is to create a concept for certain assistance solutions. Ways of imparting knowledge have to be developed and determined under consideration of knowledge from adjacent branches, as learning psychology, pedagogics or information technology. The imparted information has to be dependant on the knowledge type specifically and user profile-obtained assigned to the different ways of the knowledge imparting. According to

the knowledge type and the target suitable assistance modules for the information presentation group have to be selected.

3.2. Implementation phase

The second phase in the development of an assistance system is the implementation phase. This phase starts with analysing possible ways for applying the components of the assistance solution (as separate programs, as integral parts of CMM software, as web-based components). Each of these ways have advantages and disadvantages and they result in different restrictions when making decisions about certain assistance modules. On the base of data about application ways and information about concrete CMM system and its purpose, imparting way for each assistance module can be chosen.

After determining the design for the modules, one of most difficult phases in whole assistance solution development procedure follows – the development of the assistance modules. From the first idea up to the completion of the module, each module separately undergoes several phases: goal analysis, making of concept, educational design, technical design, implementation and evaluation of the assistance module.

The technical design of the assistance modules demands special attention since consists of several difficult tasks: clarification which media are at disposal or are necessary, determination of needed hardware components, specification of operating systems on which the modules software would be run, determination of developmental software for the module realisation and designing of a graphical user interface.

3.3. Evaluation phase

The evaluation of an advice and assistance system is not limited to the finished product; it has to be carried out in closed relationship with the steps of the above-mentioned guide. Therefore one must distinguish between formative and summative evaluation.

The formative evaluation allows testing and improving the assistance system during the development process. In this way, an optimization of the final product can be reached, which is less likely to fail under real operating conditions. The summative evaluation starts if the development of the assistance system is completed. Formative and summative evaluation do not differ in content.

For the evaluation, the assistance modules are divided into the following groups according to their essential purpose: training components, explaining components, visualisation components and electronic assistants. For each group of assistance modules a criterion catalogue can be compiled with which the evaluation is carried out.

In addition to the "group-criteria", the evaluation of certain modules can be applied additionally with criteria that are important for that module in particular. After that, it is necessary to describe the important features of certain assistance modules regarding the determined evaluation criteria. These features are further subject of evaluation.

6. CONCLUSIONS

The interest exhibited by industry indicates that there is a requirement for workstation-integrated computer-based advice and assistance systems for executing measuring tasks on CMMs. Conventional training course have the disadvantage of not being available on the CMM at the moment the problem is posed. Existing assistance systems in the current work environments on CMMs are only implemented in an unsatisfactory and fragmentary way. Therefore, there is a need for a new generation of advice and assistance systems whose requirements are defined here.

At the Chair for Quality Management and Manufacturing Metrology at the University of Erlangen-Nuremberg fundamental knowledge for the development of advice and assistance systems have been investigated in a research project. In this project, a knowledge base for “Good Coordinate Measurement Practice” has been setup. For a methodical way of developing a computer-based integrated advice and assistance system a guideline has been outlined. A further project will emphasize the implementation of assistance solutions in a software environment, the integration of a knowledge base for form testing in the base plan “Good Coordinate Measurement Practice” and strategies for encouragement of knowledge transfer by web-based e-learning for Coordinate Metrology.

The resulting method for creating the assistance systems for coordinate measurements will be applicable to other procedures, in particular to numerically controlled measuring instruments, because of the multi-faceted nature of the metrological method and the applications of coordinate metrology.

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